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Agricultural Memorandum No 923

Relationships between sunshine, cloud amounts and net long wave radiation

PART II A comparison of some formulae available to calculate net long wave radiation

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Introduction

Agricultural memorandum 893 (Barrie, 1980) investigated the diurnal and annual distribution of cloud cover and noted the factors which could be used to estimate the likely reduction in total cloud cover during the night and hence the increase in outgoing long wave radiation.

This memorandum examines and compares some of the many formulae developed to calculate the downward component of long wave radiation from clear skies, and recommends modifications to calculate the net long wave radiation by day and night, under cloudy conditions.

The formulae

Several of the more widely used formulae were chosen from the available literature. These can be used to calculate net upward long wave radiation (RLN) under clear skies by the addition of Stefan's Law to estimate the radiation from the surface (an emissivity of 1.0 has been assumed for simplicity - for practical applications a value $\sim$ 0.95 would be used).

	Downward $RL\downarrow$ (Wm^{-2})	Net RLN (Wm^{-2})	
1.	$RL\downarrow = \sigma K^4 (0.44 + 0.08 \sqrt{e})$	$RLN = \sigma K^4 (0.56 - 0.08 \sqrt{e})$	Penman (1948)
2.	$RL\downarrow = \sigma K^4 (0.60 + 0.042 \sqrt{e})$	$RLN = \sigma K^4 (0.40 - 0.042 \sqrt{e})$	Baur and Philips (1935)
3.	$RL\downarrow = -113 + 1.047 \sigma K^4$	$RLN = 113 - 0.047 \sigma K^4$	Swinbank (1963)
4.	$RL\downarrow = 1.24 \sigma K^4 (e/K)^{1/7}$	$RLN = \sigma K^4 (1.0 - 1.24 (e/K)^{1/7})$	Brutseart (1975)
5.	$RL\downarrow = \sigma K^4 (1.08) (x)$	$RLN = \sigma K^4 [1.0 - 1.08 (x)]$	Satterlund (1976)

where $x = 1.0 - EXP(-e^{K}/b)$

$RLN = RL(net) = RL\uparrow - RL\downarrow$

σ = Stefan's constant = 5.67×10^{-8} ($Wm^{-2} K^{-4}$)

e the screen vapour pressure (mb)

K the absolute air temperature in the screen (K)

b is an empirically derived constant = 2016

Equation 1, Penman (1948) uses the average values quoted by Brunt (1939).

2, after Baur and Philips (1935) uses the basic Penman equation but with different constants

3, after Swinbank (1963), has been amended for the different value for Stefan's constant which is used here

4, after Brutseart (1975) is based on the equations of radiative transfer

5, after Satterlund (1979), is an empirically derived relationship.

Comparison for the downward component $RL\downarrow$

Data were obtained from Aspendale, Australia (Swinbank, 1963), and Sidney, Montana (Aase and Idso, 1978) detailing measured values of $RL\downarrow$, screen temperature and vapour pressure. The radiation data were available over a wide range of temperatures but were selected over the range 0 - 30°C, because values outside this are not commonly found in the UK.

Typical values of $RL\downarrow$ under clear skies are shown in Table 1.

Table 1

	e = 8 mb Temp (°C)			e = 16 mb Temp (°C)		
	0	10	20	0	10	20
Penman	210	242	278	239	276	318
Baur and Philips	226	261	300	242	279	321
Swinbank	217	268	325	217	268	325
Brutsaert	236	271	310	260	299	342
Satterlund	250	290	335	261	303	305
$\sigma K4$	315	364	418	315	364	418

The measured values were plotted against the estimates using the formulae noted earlier.

All the regressions gave reasonable results with those derived by Brutsaert and Satterlund being particularly good. (Figs 1-5)

Modification of the Brutsaert formula

From fig 4 it can be seen that the Brutsaert regression slightly underestimates $RL\downarrow$, as noted also by Satterlund (1979).

A futher analysis of the data indicated that an empirical correction to the constant, 1.24, to 1.28 provided on improved fit; see fig 6.

Thus the form of the equation becomes

$$RL\downarrow = 1.28\ \sigma K^4\ (e/K)^{1/7} \qquad Wm^{-2} \qquad (6)$$

Comparison of calculated net longwave radiation from clear skies

Using the equations in the form RL (Net) = $RL\uparrow - RL\downarrow$ typical calculated values appear in Table 2.

Table 2

	e = 8 mb Temp (°C)			e = 16 mb Temp (°C)		
	0	10	20	0	10	20
Penman	105	121	139	76	87	100
Baur/Philips	89	102	118	73	84	97
Swinbank	98	96	93	98	96	93
Bratsaert	79	93	108	55	65	76
Satterlund	65	74	83	54	61	68

All the formulae give plausable results with the exception being that of Swinbank which although relatively insensitive to a change in temperature indicates a reduction in RL (net) as the temperature increases.

This shows the very critical nature of the $RL\downarrow$ calculation where there is a relative over estimation by Swinbank under warmer conditions.

Another aspect of the Swinbank formula which is unsatisfactory is its independance of changes in vapour pressure. It has been shown by many researchers, such as those quoted here, that more long wave radiation is absorbed and radiated as the water vapour content of the air increases. No account is taken of this in the Swinbank formula so further doubt must be cast on this method of calculating $RL\downarrow$.

Correction for cloud cover

The most widely made measurement relating to cloud cover is the daily total of bright sunshine. Expressed on the ratio of actual to possible hours for the day ($^n/N$) it gives a simple, albeit approximate, indication of the mean daytime cloudiness.

The cloudiness coefficient applied to the regressions is of the type

$$(a + b\ (^n/N)) \quad \text{where } a = 1-b$$

Many values have been suggested for the values of a and b

eg 0.1 and 0.9 (Penman, 1948)
0.3 and 0.7 (Mermier and Segiun, 1976)
0.2 and 0.8 (Linacre, 1968)

of these, the values of Linacre appear to the most representative and have been accepted.

The day-time expression for RL (net) now becomes, for Brutsaert.

$$RL\ (net) = \sigma K^4\ (1.0 - 1.28\ (^e/k)^{1/7}\ )\ (0.2 + 0.8\eta)\ Wm^{-2} \qquad (7)$$

where $\eta = {}^n/N$

During hours of darkness the cloud cover can usually be expected to decrease, thereby allowing a greater loss of long wave radiation from the earth's surface. To account for this, the simple correction factor of 1.12 is applied to the value for η (Barrie, 1980 leading to, for the night-time case,

$$RL\ (net) = \sigma K^4\ (1.0 - 1.28\ (^e/k)^{1/7})\ (0.2 + 0.8\eta')\ Wm^{-2} \qquad (8)$$

where $\eta' = 1.12\eta \qquad (\eta' \leq 1.0)$

Discussion

It has to be accepted that regression equations for clear-sky net radiation in terms of screen values of temperature and humidity can at best only give estimates of mean 24 hour values.

Over shorter periods departures of lapse rate from near-neutral usually lead to over estimates of incoming radiation by day and under estimates of night: (Paltridge, 1970). Adequate representation of the effects of cloud on radiation values introduces further difficulties, particularly at night.

Within these reservations equations 7 and 8 provide reasonable estimates of RL (net), and when used with the regression derived by Cowley (1978) to estimate the short wave component, with appropriate values for albedo and emissivity, a fairly accurate value for a net all-wave radiation can be calculated.

A detailed verification against measured radiation values at a met site where accurate recordings of temperature humidity and cloud cover have also been made is not yet possible as the data is not available: a limited verification will be done presently.

Any comments of suggestions on this paper should be referred to the author.

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FIG 1

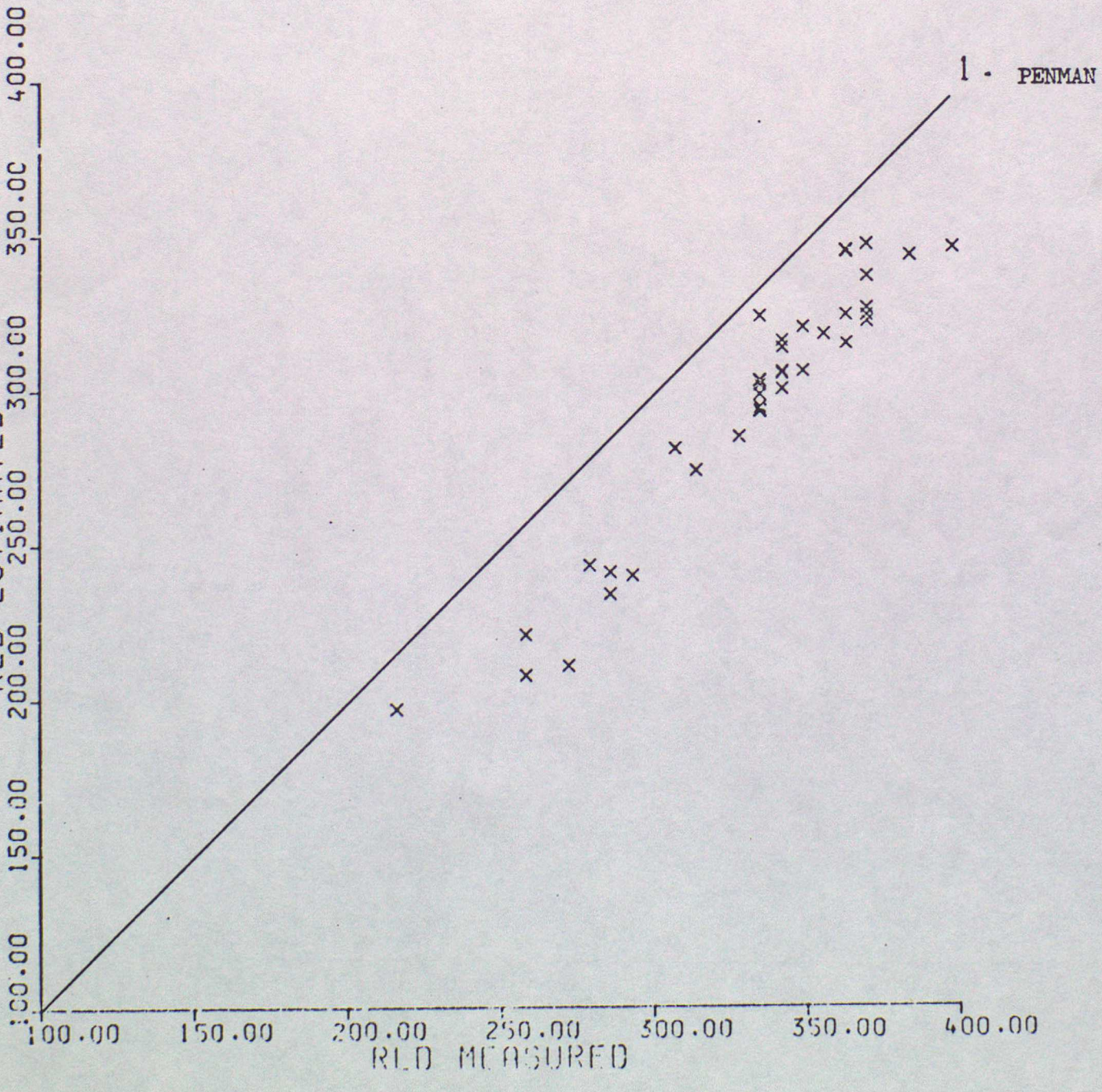

1 - PENMAN
RLD ESTIMATED
100.00
150.00
200.00
250.00
300.00
350.00
400.00
RLD MEASURED

FIG 2

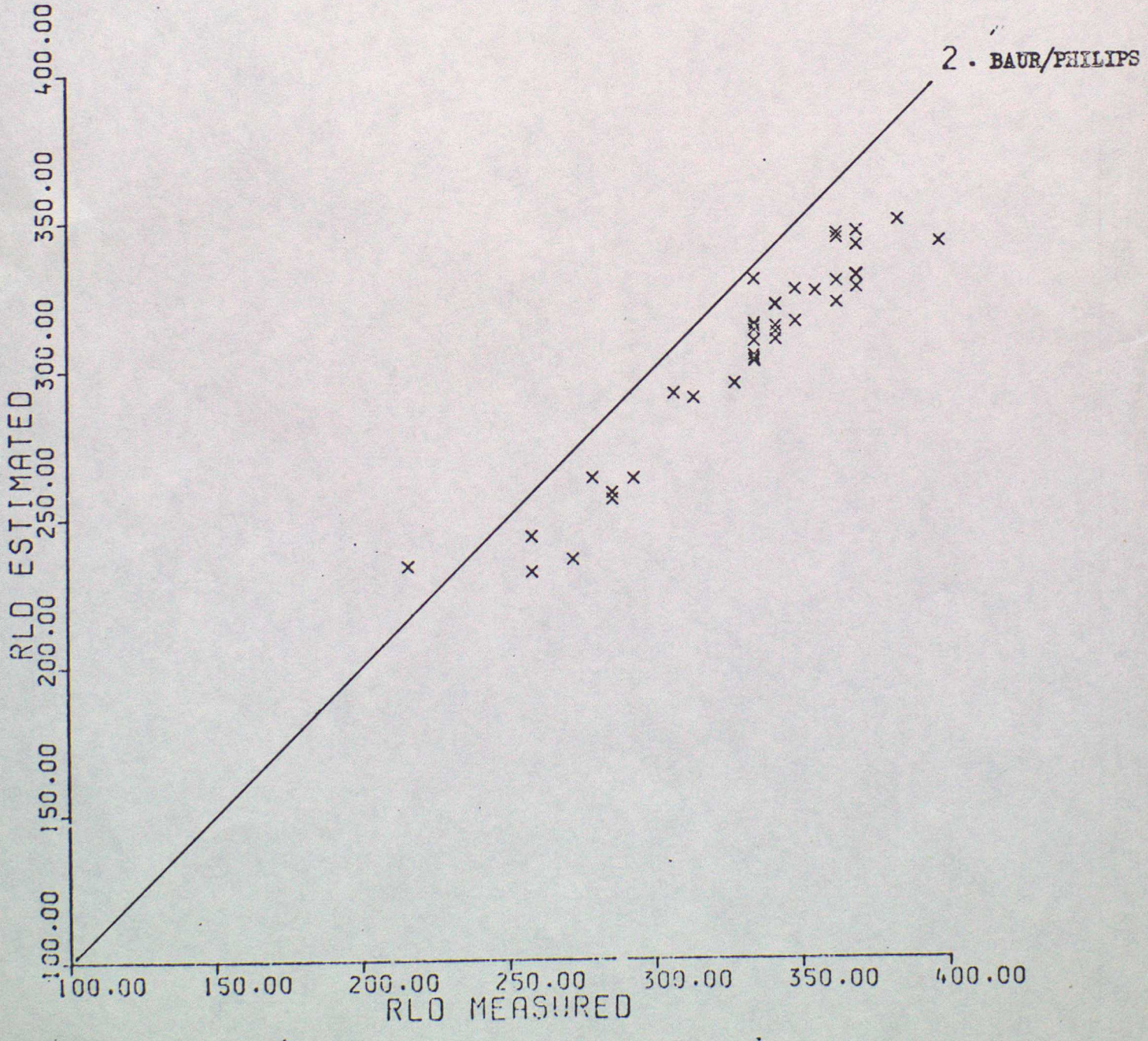

2 . BAUR/PHILIPS
RLD ESTIMATED
100.00
150.00
200.00
250.00
300.00
350.00
400.00
RLD MEASURED

FIG 3

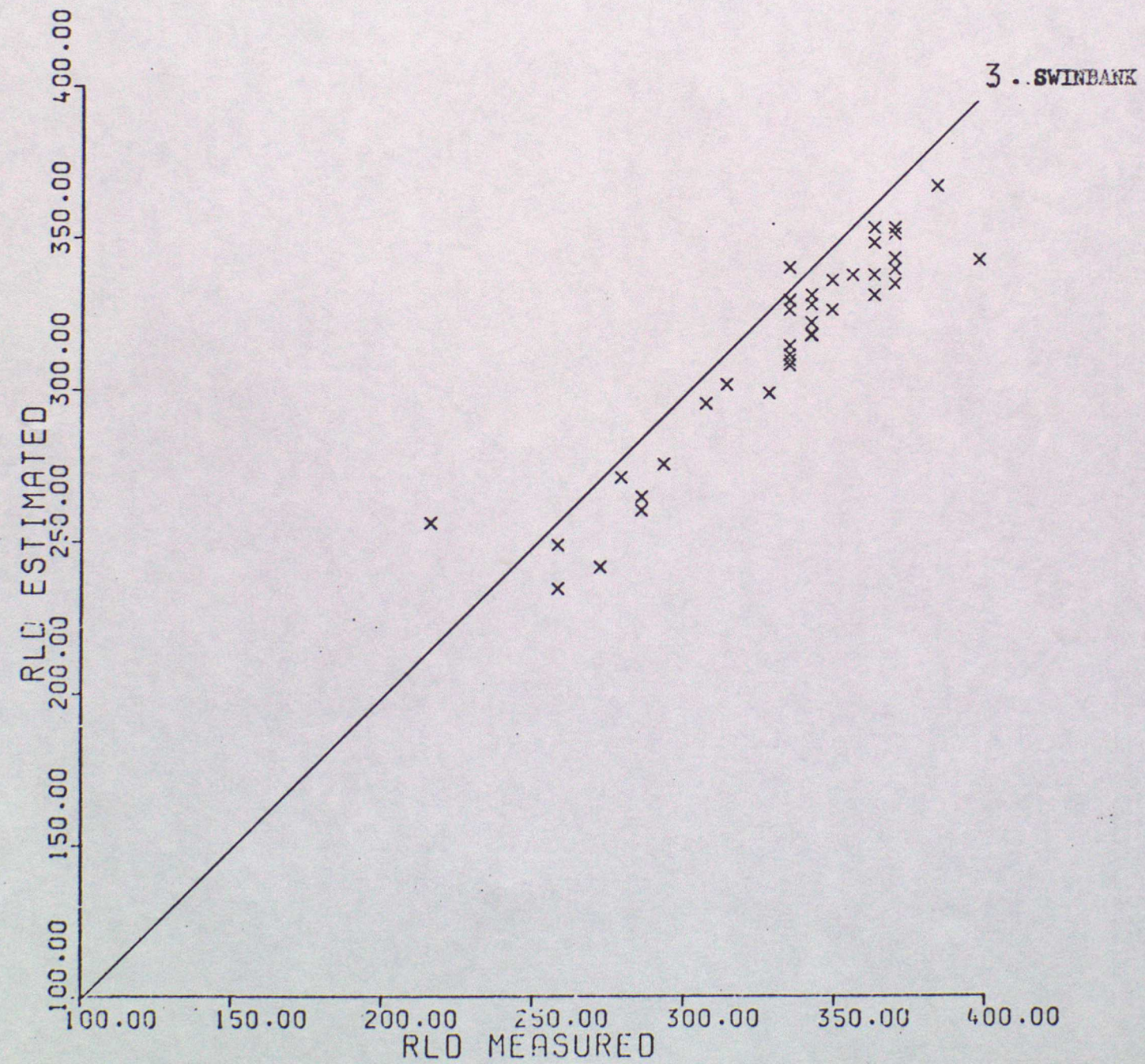

3 . . SWINBANK
RLD ESTIMATED
100.00
150.00
200.00
250.00
300.00
350.00
400.00
RLD MEASURED
100.00
150.00
200.00
250.00
300.00
350.00
400.00

FIG 4

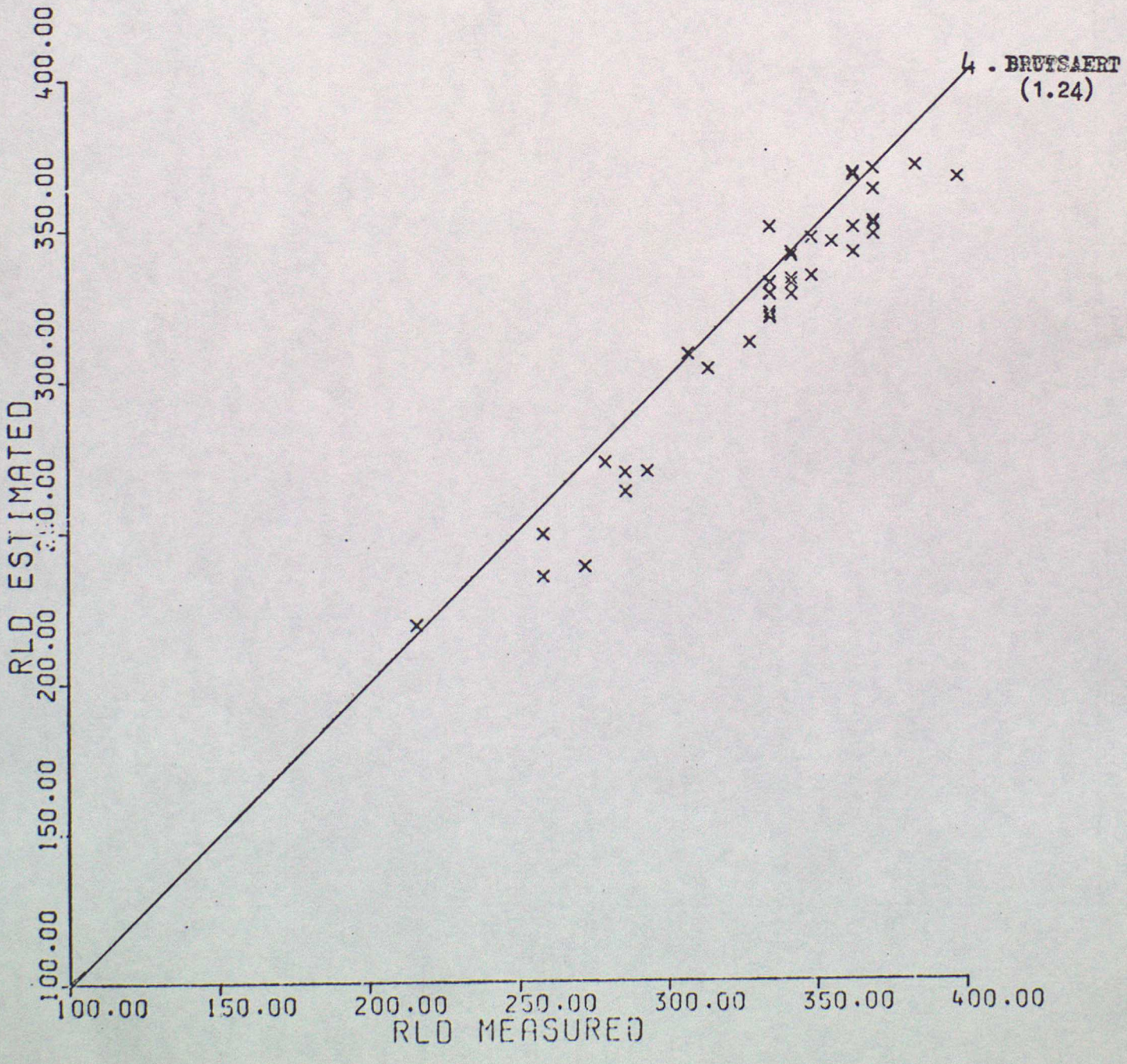

4 . BRUTSAERT
(1.24)
RLD ESTIMATED
100.00
150.00
200.00
250.00
300.00
350.00
400.00
RLD MEASURED

FIG 5

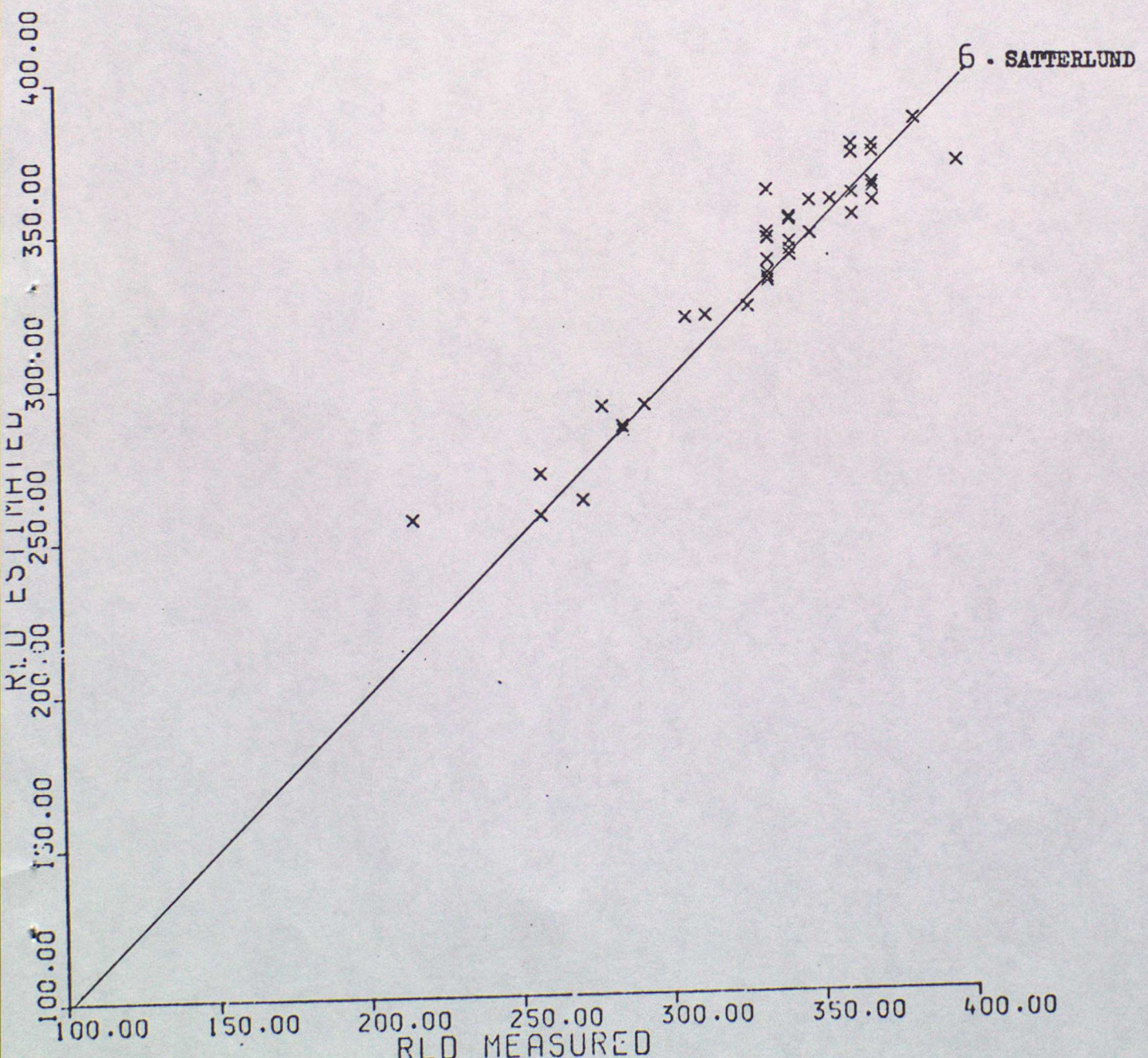
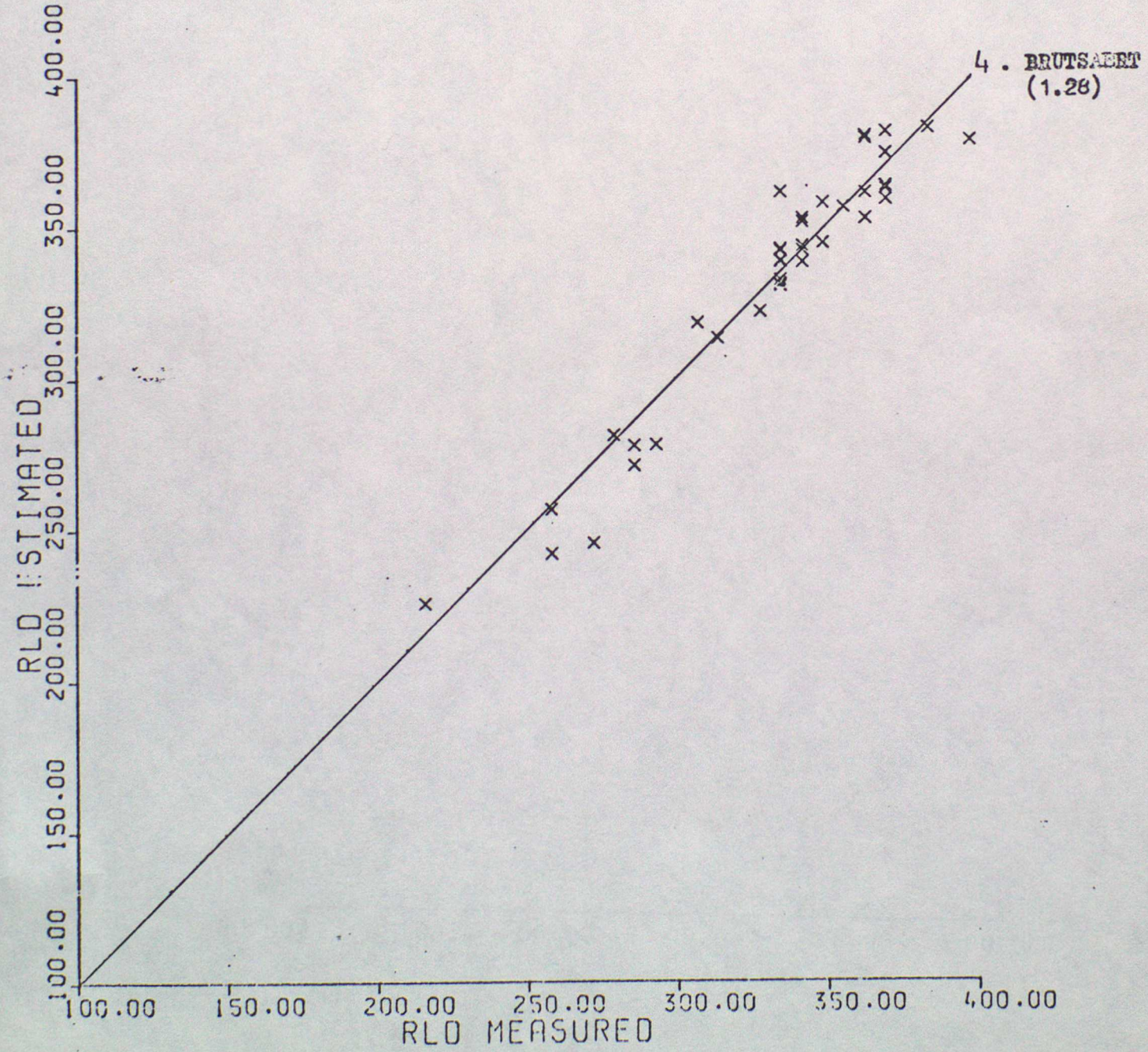

6 · SATTERLUND
RLD ESTIMATED
100.00
150.00
200.00
250.00
300.00
350.00
400.00
RLD MEASURED

FIG 6


4 . BRUTSABET
(1.28)
RLD ESTIMATED
100.00
150.00
200.00
250.00
300.00
350.00
400.00
RLD MEASURED
100.00
150.00
200.00
250.00
300.00
350.00
400.00